



ASHESI UNIVERSITY COLLEGE

**POWER QUALITY MEASUREMENTS AND MONITORING WITH SMART
TECHNOLOGY: DESIGN AND ANALYSIS WITH A SINGLE-PHASE POWER
METER**

APPLIED PROJECT

B.Sc. Electrical & Electronics Engineering

Martin Walter Ampah

2019

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METER**

**APPLIED PROJECT
CAPSTONE PROJECT**

Capstone Project submitted to the Department of Engineering, Ashesi
University College in partial fulfilment of the requirements for the award of
Bachelor of Science degree in Computer Engineering.

Martin Walter Ampah

2019

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

.....

Candidate's Name:

.....

Date:

.....

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor's Signature:

.....

Supervisor's Name:

.....

Date:

.....

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To all the people whose encouragement and academic advice helped me undertake this project, especially my supervisor, Dr. Robert Sowah.

Abstract

Electronic devices comprising of non-linear components (diodes, transistors, transformers, etc.) produce some number of harmonics in our power systems creating various voltage distortions [7]. As a result, several technical problems may arise for the device such as overheating and damage to sensitive equipment which would most likely lead to lifetime reduction to the customer's devices. To reduce the likelihood of these undesired happenings, this project seeks to develop a digital power quality analyzer that would aid customers to efficiently monitor the power flow into their devices. This would help them detect some upcoming power system errors beforehand.

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Chapter 1: Introduction

From the dawn of the industrial age, electric power has progressed to become an indispensable resource for all the world's economies. It is virtually impossible for a nation to achieve economic stability without first ensuring that it has a sustainable source of electric power generation. The needed electric power can be generated from various forms depending on the kind of generating capacities a nation or region has. These include – but are not limited to – hydro dams, thermal power plants, solar rays, etc [13].

It is important to note that the production of electric power doesn't just end with its generation from the respective producers to the usage of the various customers. But rather, a continuous and progressive effort should be made to keep the generated electric power within a state of standardized quality. This brings to notice the issue of Power Quality.

1.1 Background of Problem

Power quality (PQ) refers to a well-known term embracing all aspects associated with amplitude, phase and frequency of the voltage and current waveform in a power circuit; any issue related to voltage, current or frequency deviation that results in failure of the customer equipment is known as a power quality problem [1]. It is thus an important factor that the electric power being supplied by a registered producer to a consumer is of the desired specifications of the consumer's equipment needs. If these requirements for the desired power quality are not achieved at the consumer's end of distribution, the functioning electrical equipment will experience varied forms of disturbances or at worst, failure [2]. Every industry requiring the use of electric power from a

central grid should be concerned with this issue as it greatly affects the optimum performance of their electrical equipment daily.

1.2 Objectives of The Project Work

This capstone project in accordance with the engineering requirements of Ashesi University seeks to define a scope of the issue of power quality within power industries and develop a device to aid in its monitoring and analysis. This would begin by performing an in-depth research on some causes of the issue and their corresponding effects before finally devising a method of solving this recurring problem in the power sector.

1.3 Expected Outcome of the Project

After concluding the project, the following outcomes should have been achieved:

- A written code program – using C – to aid with the collection, monitoring and analysis of the needed parameters associated with power quality readings.
- Creation of a device for which the written program would be deployed on for the consumer's usage.
- A web application to contain a log of all incidences of any determined power quality compromise and their times of occurrence. This would be accessed by customers to act as a source of reference.

1.4 Justification/Motivation of the Project Work

Ensuring that the electric power being consumed by all forms of end users requires a continuous effort by the producers in detecting the slightest variation in components of electric power – its voltage, current, frequency and power factor (pf) – from the norm. Electric power supply

companies thus have a duty to uphold in this regard. Now consider a situation where these power supply companies fail to supply the optimum electric power needed by their consumers for a varied number of reasons. In addition to this, today's electric power consumers use a wide range of devices consisting of power electronic components that cause loads to become non-linear. Due to the substandard power quality supply and some known non-linearities, several unwanted effects arise in the consumer's electric products such as excessive heating which can drastically shorten the lifespan of sensitive equipment connected to the power system [3]. To aid with this continuous effort, this capstone project seeks to ensure accountability in power quality supply at the receiving end of the transmission system. Electric power consumers deserve to be supplied with the required quality of power from their respective suppliers after payment of their services. Thus, the project seeks to develop an efficient model of a power quality checking device which would simplify the process and not compromise on the quality of its desired measurements for the customer. These obtained measurements of the required parameters from the supply grid (values collected over a period of 2 weeks) would then be compared with the standard industry values to determine the extent of the deviation from the standard power quality supply. The obtained information can hence be used to aid users to detect existing harmonics in their power systems and enable them to take the right actions.

1.5 Materials to be Used

In addition, the known materials needed for the development of the project include (but are not limited to);

- Arduino UNO microcontroller
- ESP8266 Node MCU

- Solid Enclosure for the device
- Current Transformer
- Circuit Design and Simulation Software (preferably a license to Eagle 7.7.0)

1.6 Scope of Work

This capstone project has been divided into four main parts for completion over a designated time frame before a final submission would be presented. It will cover the following outlined points:

- Creation of a circuit to detect and digitize the desired signals of the connected load.
- Creation of a written code program – using C – to aid in the power quality analysis of the input quantities.
- Creation of a circuit for which the written program would be deployed on for the consumer's usage.
- Creating of a database to store the results of the analysis (Either locally on a personal computer or on the internet).

Chapter 2: Literature Review

2.1 Academic Paper Reviews

To ensure the successfulness of the project under discussion, similar projects already undertaken in the field of power quality and control were critically reviewed. Reviewing these papers and clearly outlining the gaps within them aided in providing some insights on what to focus on during the project completion.

The motivation for the first paper under discussion was to provide an effective means to determine the voltages and current waveforms, levels of harmonics, power factor and power consumption [1]. This information could be used to help users to detect the existing harmonics levels within their electrical systems and as a result recognize the power characteristics of their varied devices. Yue Yi, Rong Guo, Zhiqiang Liu and Ruichen Sun created the Digital Power Quality Analyzer (DPQA) to measure voltage and current signal inputs from customer loads and thus performs power quality analysis on these sampled signals. The analyzed results, which include amplitude of the current and voltage, fundamental frequency, harmonic contents, load power factor and complex power consumption are meant to reflect the characteristics of the power that supplied to the load. These results are then displayed on a custom graphic user interface (GUI). System testing was split up into two main parts: software-generated signal tests and completed system tests. The complete system test was performed after every aspect of the project was integrated together. The researchers however revealed that the results were not as accurate as that performed with a simulator. The harmonic characteristics were all understandable but the quantitative amount it measured contained a considerable amount of oversight of errors. The frequency measurement had an average error of 5%. The authors

remarked that using the same scripting language for the data analysis system and that of the internet access system minimized the hustle related with the process of transferring the data transfer from the Raspberry Pi.

The IEEE 1159 presents a recommended practice for the monitoring of electric power quality which should be followed [2]. Instruments used to monitor electromagnetic phenomena can range from simple handheld analog devices to heavy duty site installed forms. Clause 6 of the document sheds light on the proper selection of the proper type of monitoring system to be used in different situations while differentiating between the capabilities of the equipment. The paper first progresses to give a brief history of power quality monitors stating their initiation since the mid-1970s. Two kinds of monitors commonly used in these processes are handheld and permanently installed dedicated monitors. In modern times, these power systems rely on relays to acquire limited PQ data. AC Voltage and AC current are the primary two measurements for power quality phenomena. For the case of monitoring instruments, these include basic instruments such as event indicators and oscilloscopes. The first stage in the monitoring process is data acquisition, followed by database management of the waveforms and calculated parameters. In conclusion, the paper provides a summary of the details within Clause 6 of IEEE 1159 concerning the efficient monitoring of power quality systems.

In another paper, the researchers Reyes and Andres – within Chilectra, a subsidiary company of the Endesa Group, Spain – use information provided by experiments while working with their self-developed simulation tool to determine the voltage quality being distributed to their end customers in Santiago, the capital of Chile [14]. Aside that, the paper presents the main factors to be considered when taking measures to solve voltage quality problems pertaining to Chilectra's electrical system. They find their simulation providing positive results through achieving a

significant statistic (about 17% decrease in customer voltage quality issues) by changing the connected tap position of 10 distribution transformers whose end have voltage quality issues. The company thus plans to fully adopt the changes in their actual distribution network. From the analysis of the paper, I believe the characteristics of the Chilectra's simulation model can be replicated for other distribution network of companies using their specific parameters to make their services better.

Furthermore, J. Doescher, S. L. Pang and two other researchers from their investigations recognize sudden voltage dips (mainly caused by uncontrolled factors; lightning and third-party interference) as the most common power quality issues within a distribution network [3]. They support this claim by evaluating different voltage dip scenarios and analyzing their results. The solution for such a recurring problem was, the employing of VDCDs (Voltage Dip Compensating Device) as part of voltage line installation protection requirements as they are the key factors to make the project and product a success. If these products are installed at substations, they could provide a voltage dip free supply to customers at the supply-side. From the paper, employing VDCD for installation protection can be considered as an effective dip mitigation solution for the issue of power quality.

From the perspective of the distribution end of the power chain, an in-depth study was done to analyze the problem of Power Quality (PQ) in Low Voltage (LV) within weak distribution networks by the researchers Chindris, Cziker and Miron [5]. A case study for such a scenario was conducted within the power distribution system of Romania (a nation described as one of the leading generators of renewable energy in the world). According to the researchers, the most attractive solution to obtain the goal of mitigating the effects of power quality is to install at a generator's point of common coupling (PCC) a combination of both series and shunt APFs

known as a unified power-quality conditioner (UPQC). This equipment in my opinion has a high performance and the ability to mitigate almost all load current (harmonic, reactive current, unbalance and neutral current) and supply voltage (sags, swells, flicker, etc.) imperfections. With more research currently being done on the subject, this avenue proves a possible solution to aid in permanently solving this recurring problem.

Last but not the least, a study conducted by J. Won, Y. Chung and I. Moon sought to identify a method for determining the appropriate kind and rating of power quality solutions for any form of power system [6]. It suggests two techniques of reaching this goal of selecting the kind of solution; By using the power quality event cause and direction and the most commonly used method of developing custom power devices. The rating of the solution on the other hand is determined from lost energy during power quality events. From further research, a case study has shown that appropriate power quality solution can effectively remove power quality problems in power system. The purpose of the paper is to give customers a guideline for their choice and enhance the power quality level of their supply.

2.2 Gaps Identified

For the first paper of developing a Digital Power Quality Analyzer, a recognizable loop hole was found within the components selected for the project as this affected their optimum quantitative measurements collection. For instance, the researchers were only able to achieve harmonic threshold measurements of up to the 12th order instead of an estimated 20th order at the beginning of the experiment. In addition, the measurement error of $\pm 5\%$ was only maintained for frequency measures and not the other quantities.

With the research conducted on the use of VDCD's as a power quality solution, it can be inferred that the process is heavily dependent on manual analysis of the system and supplier conditions as to what type of VDCD to use. To address this, the monitoring system could be trained to analyze recurring faults and thus suggest the right kind of VDCD to use to prevent constant changes of the device and prevent voltage dips.

Chapter 3: Design

3.1 Block Diagram of the Design

To better explain the concepts involved in designing the frame of the Single-Phase Power Analyzer, a block diagram was developed help visualize its processes. This is illustrated below:

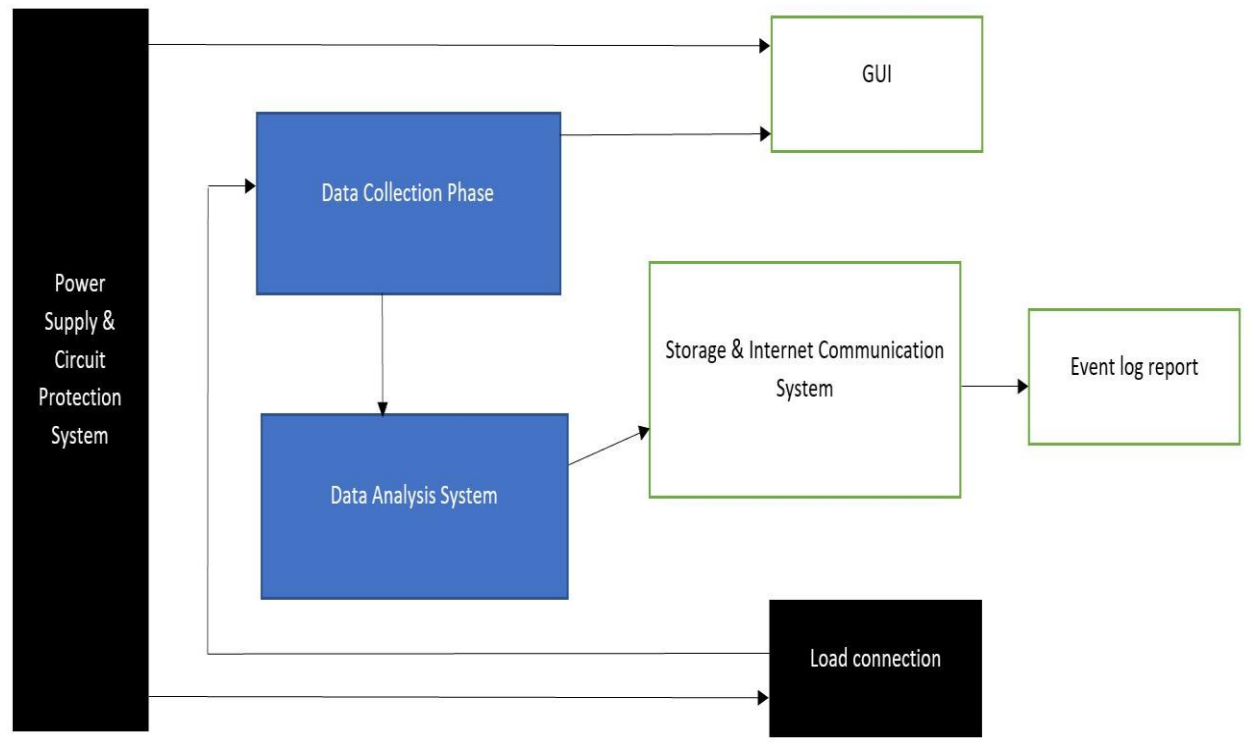


Figure 3.1: Block Diagram of Power Detection & Analysis System

Power Supply & Circuit protection System & Data Collection Phase

The Power Detection & Analysis product is first connected to a stable source of power to activate it and then, it is connected to the desired load connection via the attached ports in its circuitry. Once connected, raw data concerning the voltage, current and operating frequency of the system is collected and stored for the required processing phase.

Data Analysis System

For the data analysis phase of the system, the collected raw data values of required parameters are then used to calculate for other needed parameters of the system (i.e. Apparent, Real and Reactive powers of the system, the systems power factor (pf), etc.) and these are all compared against already set standard reference values of those needed parameters. This stage is essential in determining the amount of deviation from the ideal system operating requirements in order to devise counter measures for them.

Graphic User Interface (GUI)

These phases are linked to the designed graphic user interface (GUI) of the entire system to enable the user to interact and visualize the information being processed from the data received over time. This part of the project is ultimately designed to be user friendly and thus is less complicated to navigate through.

Storage & Internet Communication System & Event Log Report

The information produced can then be stored locally via the raspberry pi 3 memory or globally via an internet user portal system. Finally, a comprehensive report of the detection and analysis process is generated using an event log report for the time span of the process.

3.2 Product Circuitry Requirements

SD3004 SOC

The IC, SD3004, is an electric energy measurement IC with high accuracy. It is primarily used in single phase two wire electronic power meter which is the purpose of this project. It provides features such as high reliability, linearity, and stability. It belongs to the package LQFP64 [15].

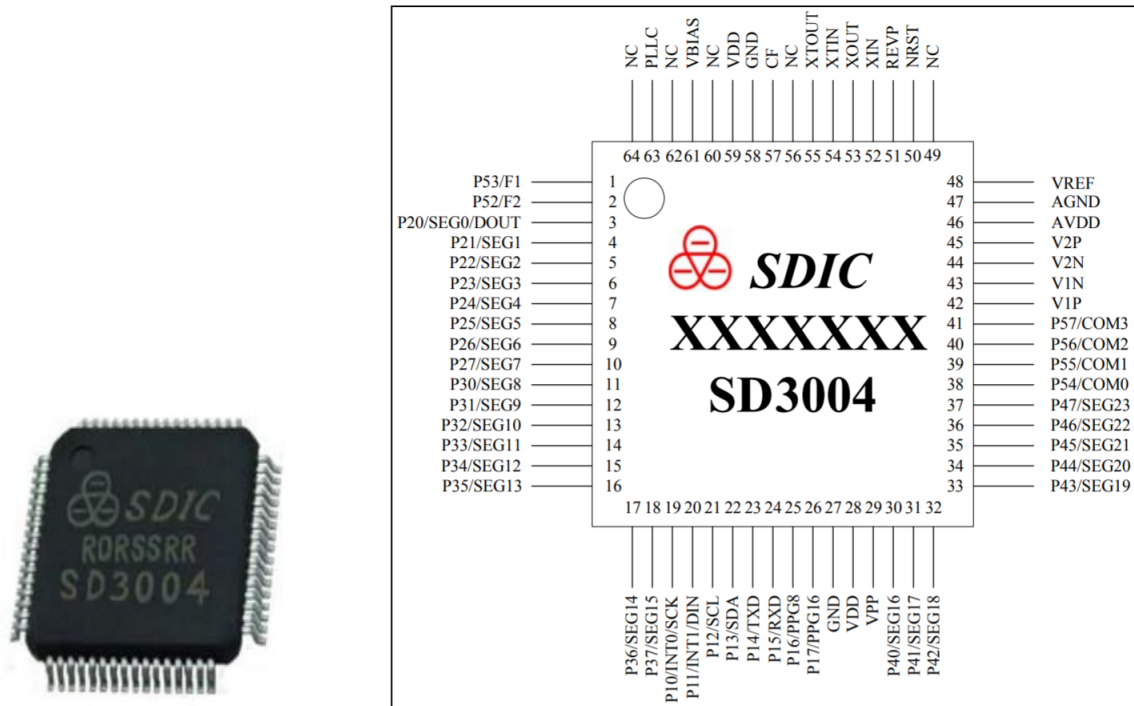


Figure 3.2: Picture and Pinout Schematic of SD3004 IC. [15]

ESP8266 Node MCU WIFI Devkit

The ESP8266 is a self-contained WIFI networking solution offering as an existing bridge from existing microcontrollers to WIFI and is also capable of running self-contained applications. Its module's breadboard friendly design also comes with a built-in USB connector (enabling a user

to activate a flash connection between the Node MCU devkit and a laptop) and a varied pin-outs [8].

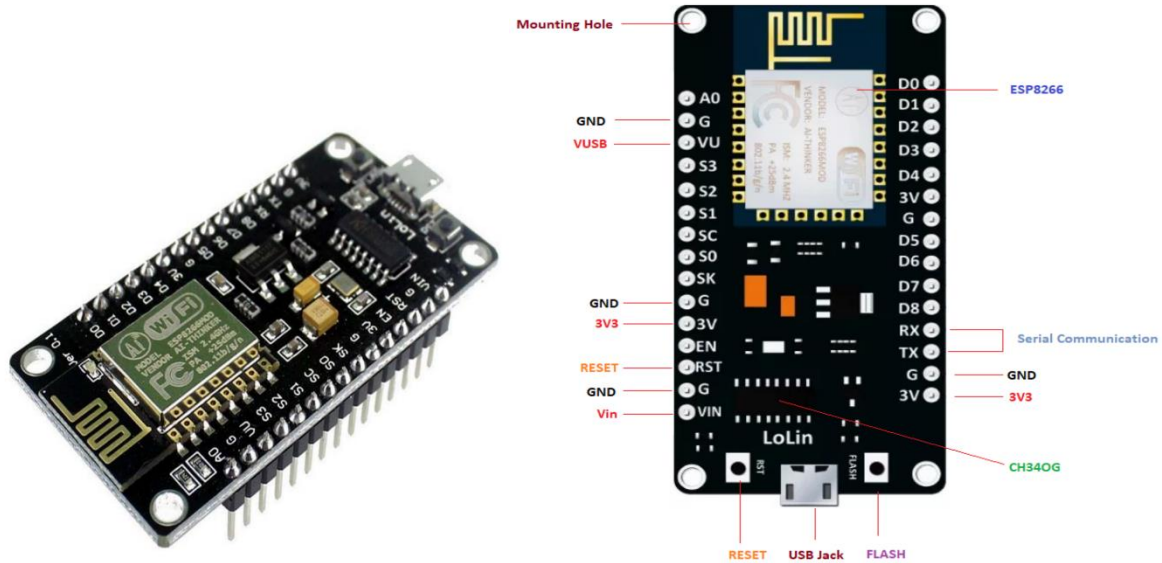


Figure 3.3: Diagram and Pinout schematic of ESP8266 Node MCU Devkit. [8]

Crystal Oscillator

This is an electronic circuit that is used to generate an electrical signal of precise frequency by utilizing the vibrating crystal's mechanical resonance made of piezo-electric material. It is purposely used for this circuit to generate a sine wave which is used to give clock pulses required for the timing synchronization of all the internal digital operations. The oscillator circuitry contains the crystal and bypass capacitors which remove higher-order harmonics from the oscillation [4].



Figure 3.4: Diagram of 32.768kHz Crystal Oscillator. [4]

PC817 Opto-isolator

This device, also known as Opto-isolator, basically provides electrical isolation between an input source voltage and an output load voltage using light. Current from the source signal can pass through the input LED which emits an infra-red light whose intensity is proportional to the electrical signal [10]. The emitted light falls upon the base of the photo-transistor, causing it to switch-ON and conduct. When the current flowing through the LED is interrupted, the infra-red emitted light is cut-off, causing the photo-transistor to cease conducting. This way, an electrical isolation of up to 10kV is attained. It is connected at the terminals connecting the circuit with the microcontroller in order to isolate the microcontroller from the effects of relatively large voltage and current values flowing through the PCB.

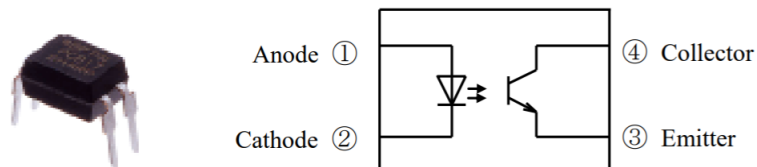


Figure 3.5: Picture and Schematic Diagram of PC817 Opto-isolator. [10]

LM78L05 Voltage Regulator

This device, designated by the part number “05”, is used to generate a constant output voltage of 5V to power the circuit. It features overload and short-circuit protection to ensure its efficiency.

The output voltage tolerance is $\pm 5\%$ over temperature.

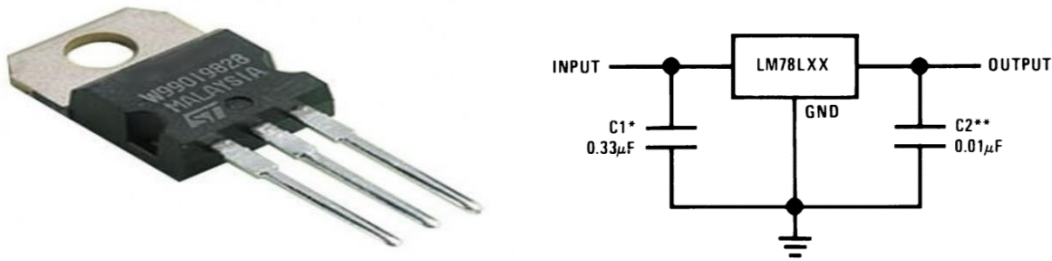


Figure 3.6: Picture and Schematic Diagram of LM7805 Voltage Regulator. [17]

Forward-biased Diode & Zener Diode

This device exhibits “dynamic resistance” properties. The voltage drop across the Zener diode will not change as the current through it changes. It aids in determining the reference operating voltage of the circuit [5].



Figure 3.7: Schematic Diagram of Zener diode. [5]

24C01SN EEPROM Array

The EEPROM array device (which can be thought of as an SD card) is used to hold configuration or other data which a user wants to be available across multiple reboots including

if the microcontroller abruptly loses power and is then powered back up. The EEPROM device was chosen for this circuit instead of a flash memory device for the sole purpose of it having more erase/write cycles as a property (approximately 1,000,000 available cycles). It belongs to the package SO-08 [9].

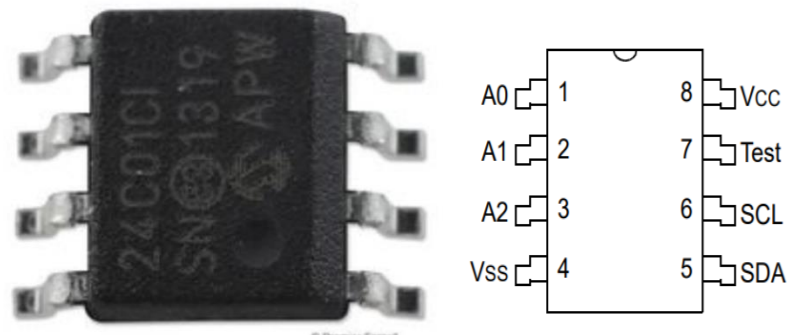


Figure 3.8: Picture and Schematic Diagram of 24C01C EEPROM Array. [9]

Tape Wound Ring Current Transformer (CT)

The tape-wound current transformer (CT) is a device which measures the current of another circuit. It is designed to produce an alternating current in its secondary winding which is proportional to the current being measured in its primary side. Current transformers reduce high voltage currents to a much lower value and provide an easier way of safely monitoring the actual electrical current flowing in an AC transmission line using a standard ammeter [12].



Figure 3.9: Tape-wound Current Transformer. [12]

3.3 Pugh Charts for Selection of Materials to be Used

In the process of determining the components and design structure of the device to be created, Pugh charts were employed in selecting these needed components based on a variety of criteria. These criteria included cost, memory capacity, accuracy, etc. depending on the component desired. These charts are illustrated below:

For Microprocessor selection:

	Baseline	Weight (1 – 5)			
Criteria	Arduino UNO		Raspberry-Pi 3	Banana Pi M3	Intel Edison
Cost	+ 5	5	+5	+5	-5
Performance (Quick response, etc.)	+5	5	+5	0	+5
Memory Capacity	+3	3	-3	-3	+3
Number of Ports for peripherals & Wireless connectivity	+4	4	+4	+4	+4
Total “+”	75		66	41	50
Total “-”	0		9	9	25
Total Neutral	0		0	1	0
Total “+” and “-”	75		57	32	25

Table 3.1: Pugh Chart for Microprocessor Selection

For Voltage Regulator selection

	Baseline	Weight (1-5)	Alternatives		
Criteria	LM7805		MAX603	MAX1615	MAX724
Cost	+3	3	+3	+3	+3
Size	+5	5	0	+5	+5
Feasibility	+4	4	+4	0	0
Installation	+1	1	-1	-1	-1
Accuracy	+3	3	0	+3	0
Cost					
Total “+”	60		25	43	34
Total “-”	0		1	1	1
Total Neutral	0		2	1	1
Total “+” and “-”	60		24	42	33

Table 3.2: Pugh Chart for Voltage Regulator Selection

For Product enclosure selection:

	Baseline	Weight (1-5)	Alternatives		
Criteria	Polyamide (PA)		Polycarbonate (PC)	Acrylonitrile Butadiene Styrene (ABS) + PC	SEBS (Styrene Ethylene Butadiene Styrene)
Thermal Transference Capabilities	+5	5	+5	+5	+5
Price	0	4	0	+4	0
Aesthetics	-1	5	+5	+5	-5
Environmental Resistance	0	5	+5	+5	+5
Total “+”	25		75	91	50
Total “-”	-5		0	0	-5
Total Neutral	2		1	0	1
Total “+” and “-”	20		75	91	45

Table 3.3: Pugh Chart for Product enclosure selection

For Integrated Circuit (IC) chip used:

	Baseline	Weight (1-5)			
Criteria	SD3001			SD3003	SD3004
Cost	+3	3		+3	+3
Size	+5	5		+5	+5
Feasibility	0	4		0	+4
Installation	-1	1		-1	+1
Accuracy	+3	3		+3	+3
Total “+”	43			43	60
Total “-”	-1			-1	0
Total Neutral	1			1	0
Total “+” and “-”	42			42	60

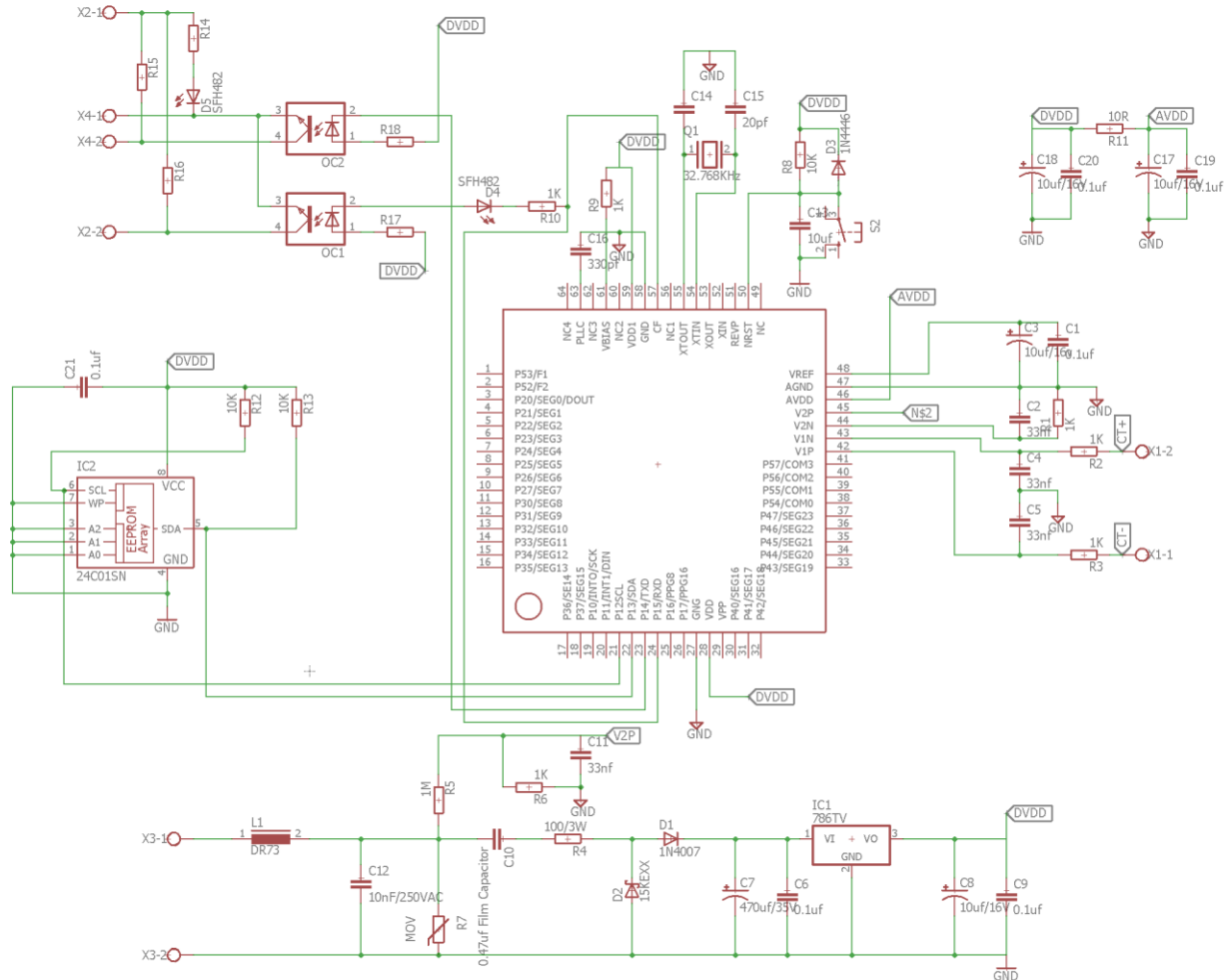
Table 3.4: Pugh Chart for Integrated Circuit Selection

3.4 Circuit Design Schematic and PCB Layout

In designing the Single-Phase Power Analyzer circuit schematic, the electronics software, *Eagle*

7.7.0 Standard version, was used with the required permissions obtained from the institution.

Figure 2 below illustrates the schematic of the design with the required components and their corresponding values needed to make it function as expected.

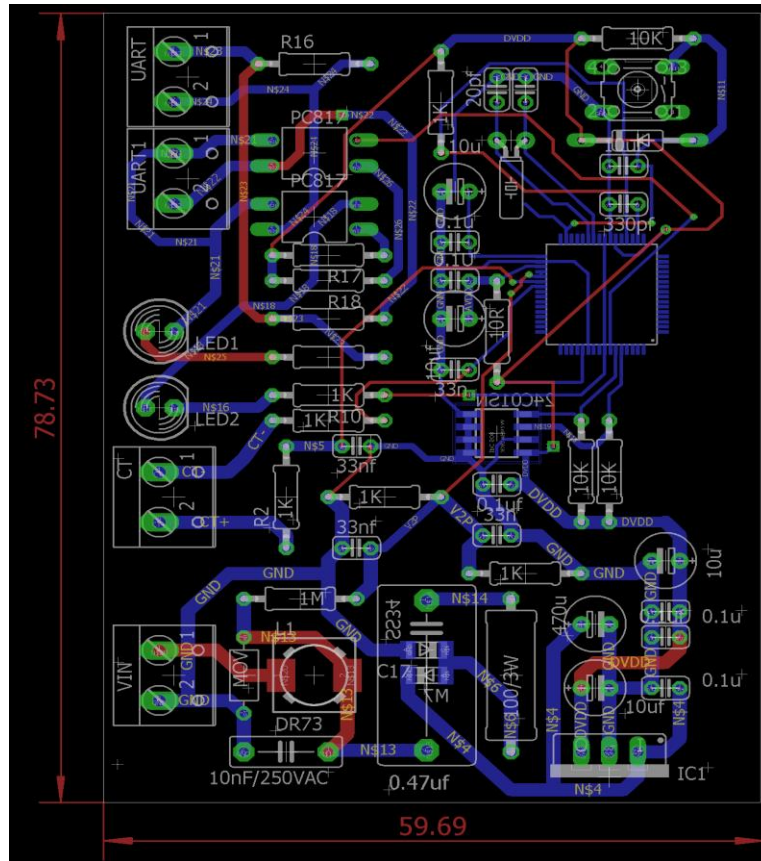


pins on the EEPROM used. The SDA is a bidirectional pin used to transfer addresses and data into and out of the device. It is designed as an open drain terminal and thus, the SDA requires a pull-up resistor to VCC. The SCL pin is also used to synchronize the data transfer to and from the device. Pins V1N and V1P (current negative and positive inputs respectively) serve as the connection points for the terminals where the current transformer would be attached. Pins V2N and V2P (voltage negative and positive inputs respectively) serve as the connection points for the terminals where the considered load connected to the power supply would be attached. The NRST pin on the SD3004 chip is connected to a push down button (normally opened in operation) to enable a user to reset the device before, during or after usage. The crystal oscillator used (of value 32.768kHz) is connected in parallel to pins XTIN and XTOUT of the SD3004 IC chip.

Shifting the focus to the development of the required Printed Circuit Board (PCB), the components were arranged based on the following criteria; their functionality within the circuit, the amount of current being drawn by each device, the closeness of the wiring connections between any number of devices and last but not the least, the minimum clearance needed for the placement of each device. The PCB was designed with two layers for current flow; the Top layer (denoted by red markings) and the Bottom layer (denoted by blue markings). The PCB was also designed with dimensions 78.73 x 59.69 mm in order to reduce the bulkiness of the product. For the processing of the board to be manufactured, Gerber files were generated for each segment and layer of the PCB.

When tracing the desired current paths for the PCB, it was important to not use 90-degree trace angles. This is because these traces have the likelihood of being etched narrower than that of a standard trace width [11]. And at worst, this could result in short circuiting of the board. In

The design for the circuit was then finalized and printed on a PCB which is has been illustrated below (Top layer view and Bottom layer view respectively):



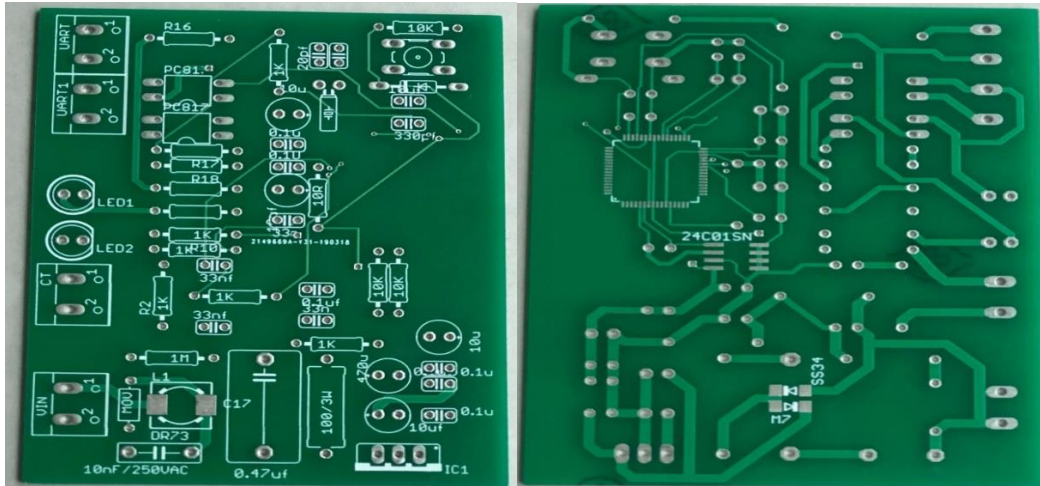


Figure 3.12: Top and Bottom Layer views of the PCB respectively

The individual components were then soldered (with some requiring to be surface mounted on the board) at their various designated areas on the board for immediate testing of the system. The final view for the board with the components soldered on is shown in the figure below:



Figure 3.13: PCB with Soldered components

3.5 Interfacing the Circuit with the ESP8266 Node MCU

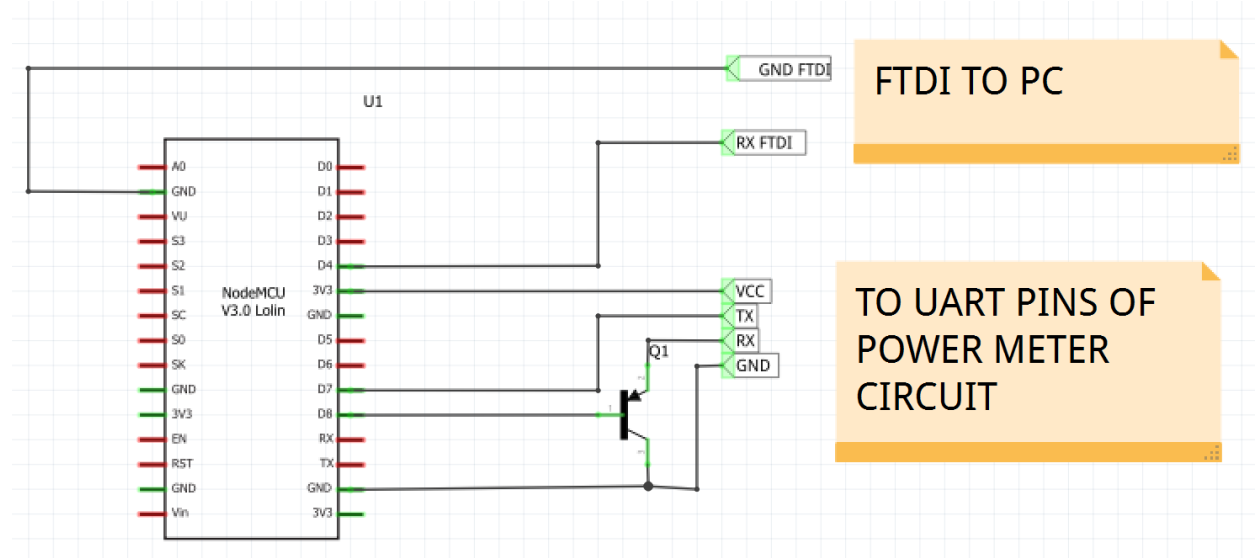


Figure 3.14: NodeMCU connection to Power Quality Meter Circuit. [8]

Using an FTDI serial to USB cable, the Node MCU is connected to a personal computer (PC) using its ground (GND) and receiver (RX) serial pins directly interfaced with its GND and D4 pins respectively. The power quality meter circuit is also connected to the ESP8266 Node MCU through its four UART pins provided in the design. This is to enable communication of obtained data between the Node MCU and the developed circuit. VCC of the UART is directly connected to the 3V3 pin of the ESP8266. The TX pin (Transmitter) is also directly connected to the D7 pin of the ESP8266 Node MCU. However, for the RX (Receiver) and GND (Ground) pins of the power quality meter circuit, these are first connected to a PNP 2N907 transistor (RX to the emitter, GND to the collector). The base of the transistor is connected to the D8 pin of the Node MCU with the collector end connected to the GND pin of the same device. The purpose of the transistor in the circuit is the act as a switch in order to help with the resetting of the circuit during operation.

3.6 Programming of the Node MCU with Arduino IDE

Programming of the Node MCU was done using Arduino IDE with all the necessary files downloaded and installed to initialize its operations. The Arduino library for the “*pzem-004t*” power meter was downloaded and used accordingly in this process as the developed circuit communicated using similar commands as it did. The Pzem-004t is a Power Metering circuit developed by the electronics company, Peace fair. Below is an illustration of the commands used to program the ESP8266 Node MCU with the Arduino IDE.

```
#include <PZEM004T.h> // include the arduino library for pzem004t to be interfaced with the circuit

/*
  Using the ESP8266 hardware serial with PZEM004T

  It should be noted that gpio15 pin must be pulled LOW on esp start, otherwise it won't boot from the required eeprom.
*/

HardwareSerial hwserial(UART0); // Use hwserial UART0 at pins GPIO1 (TX) and GPIO3 (RX)
PZEM004T pzem(&hwserial); // Attach circuit to hwserial ESP8266
IPAddress ip(192,168,1,1);

bool pzemrdy = false;

void setup() {
  hwserial.swap(); // (optionally) swap hw_serial pins to gpio13(rx),15(tx)
  Serial1.begin(115200); // Since UART0 is occupied with power meter circuit, we use UART1 to output data to serial monitor
                        // UART1 uses hwserial at pin GPIO2
  while (!pzemrdy) {
    Serial1.println("Connecting to Power Meter Circuit...");
    pzemrdy = pzem.setAddress(ip);
    delay(1000);
  }
}

void loop() {

  float v = pzem.voltage(ip);
  if (v < 0.0) v = 0.0;
  Serial1.print(v);Serial1.print("V; "); // Reading of voltage(V) values

  float i = pzem.current(ip);
  if (i >= 0.0){ Serial1.print(i);Serial1.print("A; "); } // Reading of current(A) values

  float p = pzem.power(ip);
  if (p >= 0.0){ Serial1.print(p);Serial1.print("W; "); } // Reading of power(W) values

  float e = pzem.energy(ip);
  if (e >= 0.0){ Serial1.print(e);Serial1.print("Wh; "); } // Reading of Watt hour(Wh) values

  Serial1.println();

  delay(7,200,000);
}
```

Figure 3.15: Arduino Code for Communicating with the ESP8266 Node MCU

3.7 Product Enclosure Design

For the enclosure of Power Quality Analyzer, research was done as to how the product would be used, the adequate temperature conditions for its usage, the desired weight of the product and materials ability to withstand high impact drops. As a result, the thermoplastic compound of Polycarbonate (PC) and Acrylonitrile Butadiene Styrene (ABS) was chosen from the suggested list because of its desired properties such as high impact strength, good thermal stability as well as good resistance to chemicals [16]. This compound material is best suited for indoor use although it can also be used outdoors. It comes with a flame resistance of up to UL 94 V-0 and can stand moderate corrosive conditions.

A SolidWorks design of the enclosure was thus done to visualize the material's purpose in the project and this is illustrated below:

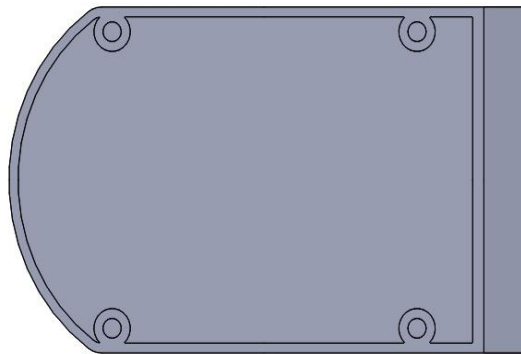


Figure 3.16: Bottom view of the enclosure



Figure 27: Side view of the enclosure

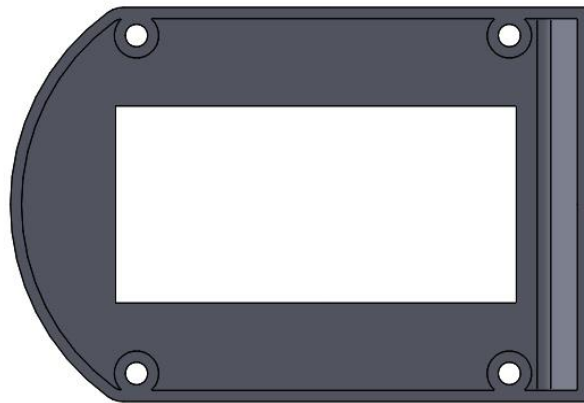


Figure 3.18: Top view of the enclosure

The entire enclosure is of dimension; 145 x 90 x 40 mm (length, breadth and height respectively). It has four through holes of diameter 3.5 mm to allow the screwing of the top layer to the bottom layer in order to ensure rigidity of the product. It possesses a cutout rectangle to enable space for a 19" 1280 x 1024 resolution programmed LCD screen to fit perfectly for the user to access.

Chapter 4: UI Specifications for Registered Users

4.1 Creation of a New User Profile

After purchasing the Power Quality Meter and using it accordingly to read the required data, then comes some questions of accessing one's information on a global scale, *“What if a consumer after setting up and using the product, wants to access his/her power quality data log wherever he/she is in the world through the internet? What level of detail concerning the analysis would be available for his/her viewing? How easy would it be for a consumer to register for this service and access the required information? Would the developed UI be easy to navigate for him/her?”*.

In the development of the User Interface (UI) for registered consumers, HTML was used. In creation of the sign-up page by new users of the product, the program requests that the user inputs some important information about him/her (firstname, lastname, email, country of residence and password) to create a generic profile for access to their details. This personal data is added to a created database (constructed using *mysql*) so as to store the valid inputs and refer to them when needed. In this regard, anytime the registered user logs-in to access his/her details with the valid arguments, a “token” is generated to ensure access for the time period of the session while online and then is erased when the user logs-out. This process is done using the `“(app.secret_key.decode('UTF-8'))` command. These setups are illustrated in figure 14 and figure 15 below:

```

@app.route('/signup', methods = ['GET','POST'])
def signup():
    if request.method == 'POST':
        session['token'] = request.args.get(app.secret_key.decode('UTF-8'))
        firstname = request.form['firstname']
        lastname = request.form['lastname']
        email = request.form['email']
        country = request.form['country']
        password = request.form['password']
        tur = mysql.connection.cursor()
        dets = tur.execute('INSERT INTO user(firstname, lastname, email, country, password) Values("%s", "%s", "%s", "%s", "%s")'%(firstname, la
        mysql.connection.commit()
        tur.execute('SELECT * FROM user WHERE email = ("%s")'%email)
        Data = tur.fetchall()
        return jsonify({'ResponseMessage' : 'Signup Successful', 'Responsecode' : '200'}, {'Data' : Data})

```

Figure 3: Sign-up program for New Users

```

def token_required(f):
    @wraps(f)
    def decorated(*args, **kwargs):
        token = request.args.get('token')

        if not 'token':
            return jsonify({'message' : 'Token is missing!'}), 403

        try:
            data = jwt.decode(token, app.config['SECRET_KEY'])
        except:
            return jsonify({'message' : 'Invalid token'}), 403

        return f(*args, **kwargs)

    return decorated

```

Figure 4: Generation of token for User profiles

Once the user has been successfully registered on the platform, he/she would then be required to sign-in to the service by typing a valid input into the spaces presented on the webpage: a valid email address with the valid corresponding password. This data is then used to search through the database to check if indeed he/she is a registered consumer. After the details have been verified, the message “Login Successful” is displayed for the user to confirm his/her access. However, if the details failed to be verified through the database, the message “Unable to Login” would be displayed for the user. This except of the code is illustrated in Figure 16 below. After the user logs-in and checks all the necessary details to his/her satisfaction, the individual could then log-out of the online system by clicking the “Log-out” button on the viewed dashboard.

Once this is clicked, the initial token generated for the user at the point of log-in into the system is taken out by the function “session.pop(‘token’, None)” to signify an end to a verified information access session for the user. This is illustrated in the code block of Figure 17. The system then takes the user back to the “Sign-in” page for new details to be typed and verified by the database to initiate another authorized access session.

```
@app.route('/login', methods = ['GET','POST'])
def login():
    if request.method == 'POST':
        email = request.form['email']
        password = request.form['password']
        tur = mysql.connection.cursor()
        if (tur.execute('SELECT email, password FROM user WHERE email = ("%s") AND password = ("%s")'%(email, password))):
            Data = tur.fetchone()
            session['token'] = request.args.get(app.secret_key.decode('UTF-8'))
            return jsonify({'ResponseMessage' : 'Login Successful' , 'Responsecode' : '200' } , {'Data' : Data})
        else:
            return jsonify({'error' : 'Unable to Login!'})
    return render_template('login.html')
```

Figure 5: User Login Program

```
@app.route('/logout')
def logout():
    session.pop('token', None)
    return jsonify({'message' : 'Logged out'})
```

Figure 6: User Logout Program

Chapter 5: Results

5.1 Data Values Obtained from Power Meter Circuit

The Serial command prints the required data values on the Arduino's IDE. With this done, the code is then compiled and uploaded unto the ESP8266 Node MCU module to obtain the need data. The output from the UART pins is fed and read by the electronics software Real Term to accurately determine the resulting quantities and this is shown in the figure below:

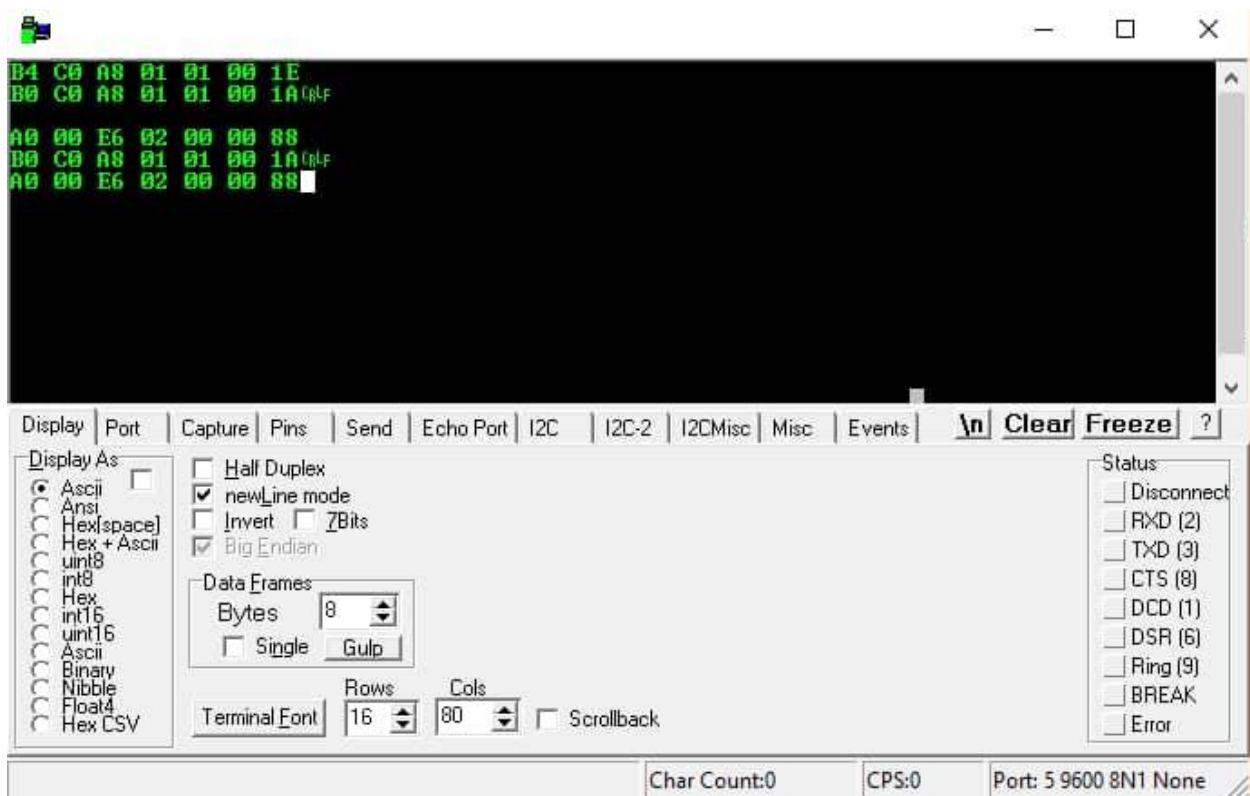


Figure 5.1: Real Term Program window

The data is produced in the ASCII format as shown above. The first column of ASCII values shown represent “heads” all of which have their distinct interpretations as the remaining values on the screen. This is further explained in the table below:

NO.	function	Head	Data1- Data5	Sum
1	voltage	B0	C0 A8 01 01 00 (Computer sends a request to read the voltage value)	1A

		A0	00 E6 02 00 00 (Meter reply the voltage value is 230.2V)	88
2	current	B1	C0 A8 01 01 00 (Computer sends a request to read the current value)	1B
		A1	00 11 20 00 00 (Meter reply the current value is 17.32A)	D2
3	Active power	B2	C0 A8 01 01 00 (Computer sends a request to read the active power value)	1C
		A2	08 98 00 00 00 (Meter reply the active power value is 2200w)	42
4	Read energy	B3	C0 A8 01 01 00 (Computer sends a request to read the energy value)	1D
		A3	01 86 9f 00 00 (Meter reply the energy value is 99999wh)	C9
5	Set the module address	B4	C0 A8 01 01 00 (Computer sends a request to set the address, the address is 192.168.1.1)	1E
		A4	00 00 00 00 00 (Meter reply the address was successfully set)	A4
6	Set the power alarm threshold	B5	C0 A8 01 01 14 (computer sends a request to set a power alarm threshold)	33
		A5	00 00 00 00 00 (Meter reply the power alarm threshold was successfully set)	A5

Table 5.1: ASCII table for Real Term communication

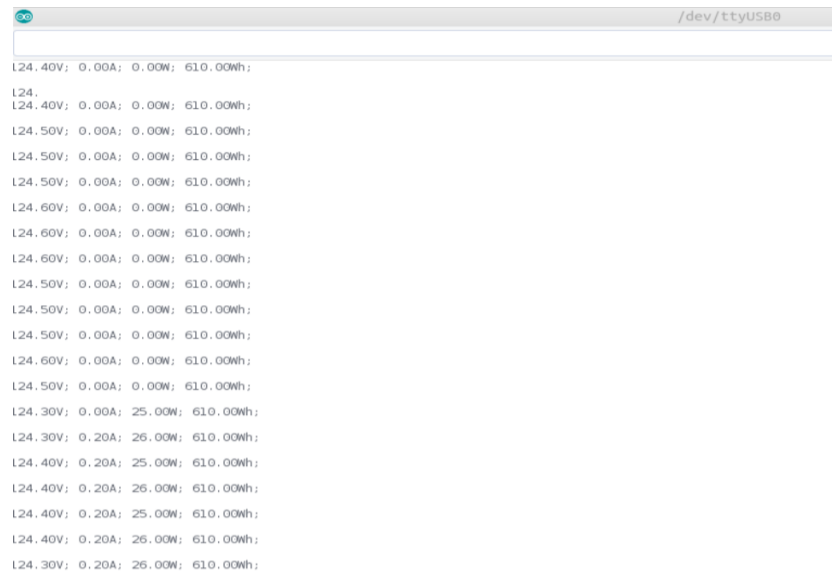


Figure 5.2: Results from the Arduino IDE Serial Monitor

The information displayed is provided in columns of the following order; Voltage (V), Current (A), Power consumed (W) and Watthour (Wh). As stated earlier this information is provided in rows at periodic intervals of 2 hours (7,200,000 ms). Within this period, every row of information obtained from the device is stored within their respective categories on the created database for the project. The online open source database was created using MySQL with PHP as the programming language. Data on this platform are stored categorically using tables. In this case, the tables used were that for Voltage (V), Current (A), Frequency (Hz), and Power (Watts). This database allows users access their power quality history records online within any part of the world and at any given time. This is illustrated below as follows:

voltage	current_data	power	frequency	time_data
235	1.3	26	49.7	8
235	1.29	25	49.8	2
234	1.3	24	49.5	10
237	1.28	24	50.1	4
236	1.29	21	50.3	6

Figure 5.3: Database created to store values for the desired quantities testing period of a load

5.2 New User Profile Creation Interface

With the purchase of the device comes instructions for accessing one's data records online.

Once a consumer purchases the device, they would be required to access the product's webapp to register as a new user. Typing the correct website address on the address bar would lead users to the webapp where they would be asked to type in a valid email with the a given passcode provided with the product to setup their online profiles. If a user has already been registered unto the system, he/she can type in the required details to gain access to the necessary details presented on the platform. For new users, they are required to click the "Create your Account" link to officially register on the platform before proceeding. This is illustrated in the Figure 23 below:

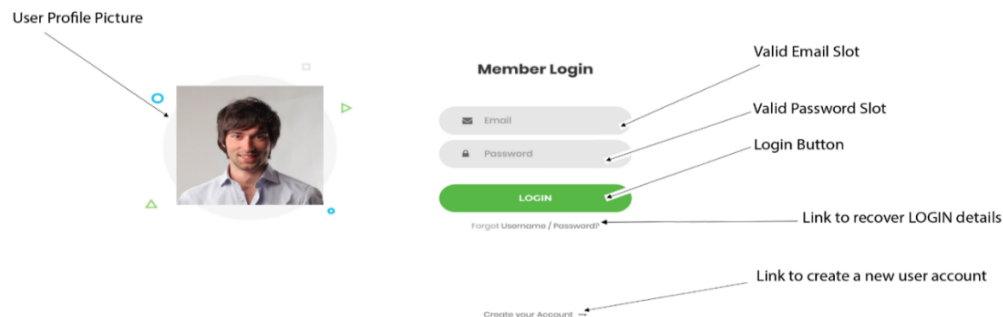


Figure 5.4: Log-in page for Registered User

Clicking the link leads new users to the screen below where they are enabled access to create their new profiles on the system. The valid details to be entered are, the preferred User Name of the consumer, a valid email address for communication and the user's preferred password for the system access. These details are then stored categorically on the database for records and used as a reference for enabling authorized access unto the system.

firstname	lastname	email	passwd
ama	carter	amac1@gmail.com	into2
elorm	addo	eladdo@gmail.com	aitrav20
iohn	bom	ihom@yahoo.com	iahbom14
kwame	addo	kaddo@gmail.com	ka12
tracv	kvei	trakvi@yahoo.com	outro225
NULL	NULL	NULL	NULL

Figure 5.5: Database created to store the required registered consumer details

By clicking the “Choose File” for and avatar, the user is allowed to select his/her profile picture to complete their registration on the system.

The screenshot shows a registration form titled "Create an account" on a dark blue background. The form contains the following fields and elements:

- User Name**: A text input field with an orange arrow pointing to it from the label "Valid User Name".
- Email**: A text input field with an orange arrow pointing to it from the label "Valid Email address".
- Password**: A text input field with an orange arrow pointing to it from the label "Valid Password".
- Confirm Password**: A text input field with an orange arrow pointing to it from the label "Password Confirmation".
- Select your avatar:**: A label followed by a "Choose File" button and the text "No file chosen". An orange arrow points to the "Choose File" button from the label "Profile picture (avatar) selection".
- Register**: A large blue button at the bottom with an orange arrow pointing to it from the label "Registration Button".

Figure 5.6: Registration of a new User unto the service

Once done, the user would be directed to the page below in order to choose a profile picture and then officially enter his/her login details once to more to sign-in.

Once the new user is done registering and logs-in officially, he/she is then welcomed to a dashboard screen with an easy to use interface made up of buttons and graphs for he/she to navigate through. This is illustrated in Figure 25 below.

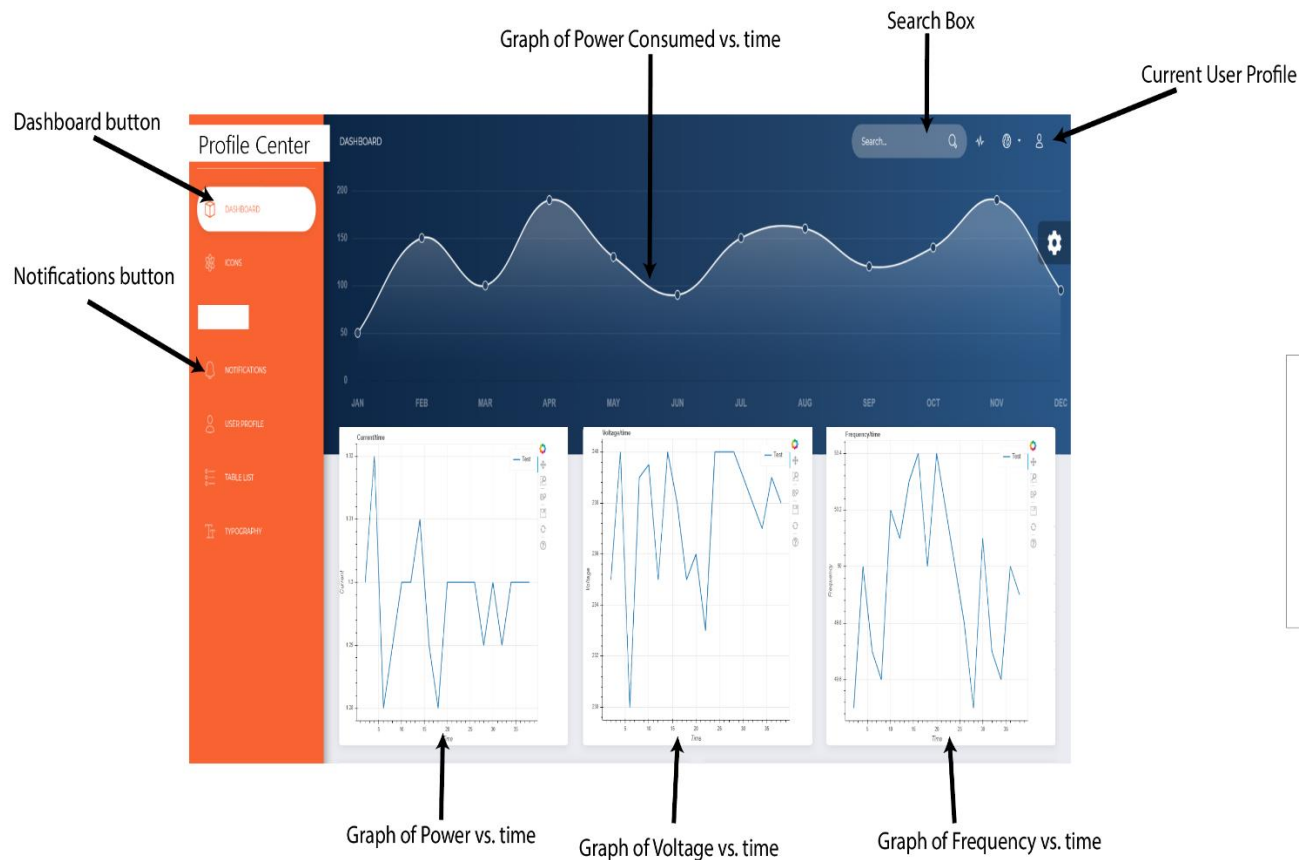


Figure 5.6: User Dashboard Illustration

On the left-hand side of the dashboard screen, the user would be able to view and access three buttons; The Profile button, the Dashboard button and the References and % Deviation button.

The Profile button allows users the access to edit their personal details uploaded and presented on the platform for better recognition as well as service provision.

Clicking the Dashboard button enables a user access to a webpage displaying all relevant information concerning the service provided. Such displayed information includes periodically updated graphs of Voltage (V) vs. Time (2hrs), Current (A) vs. Time (2hrs), Frequency (Hz) vs. Time (2hrs) and Power consumed (W) vs. Time (2hrs). This is clearly illustrated in the Figure 5.5 above.

Clicking the References and % Deviation button brings the users to a page showing the various standard reference values for the measured quantities, the average values of the quantities collected over the testing period and the calculated deviation of these measured values from the desired numbers. As shown (for illustration purposes), the reference value of that of voltage is given as 240 V with the average voltage value over the **testing period as 231.5 V**. Thus, the deviation of this value from its desired counterpart is calculated as the absolute value of the average value subtracted from the reference which is all divided by the reference value and multiplied by 100%. This is shown as:

$$\left| \frac{\text{Desired Value} - \text{Average Value Obtained}}{\text{Desired Value}} * 100 \% \right|$$

Thus. in this case, the deviation is given as:

$$\left| \frac{240 \text{ V} - 231.5 \text{ V}}{240 \text{ V}} * 100 \% \right| = \mathbf{3.5417\% \text{ Deviation}}$$

Again, the reference frequency of the quantities being supplied is given as 50 Hz however, the average frequency value obtained after the testing period is given as 50.35 Hz. This results in a deviation of:

$$\left| \frac{50 \text{ Hz} - 50.53 \text{ Hz}}{50 \text{ Hz}} * 100 \% \right| = \mathbf{0.0106\% \text{ Deviation}}$$

Graphs of these calculated Deviations vs. Time (2hrs) are then produced and plotted with their respective reference values noted on them. These are illustrated below as shown:

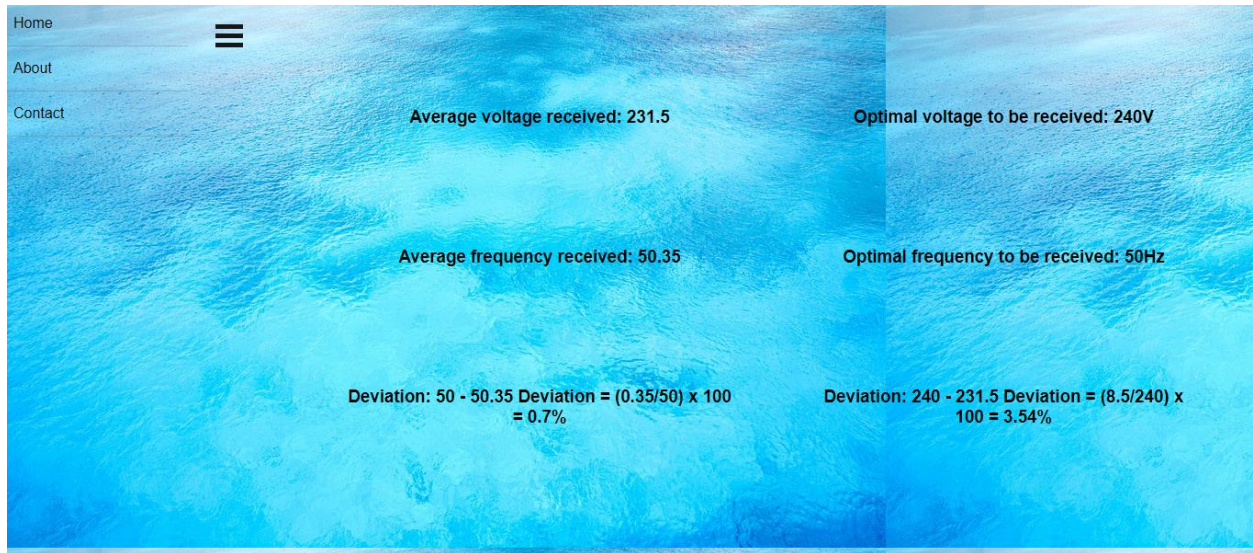


Figure 5.7: Reference and Deviation page of the Web app

Chapter 6: Conclusion

6.1 Discussion

With reference to the project's scope set in the initial chapter of this report (which served as the benchmark for measuring the successfulness of the project), the project was accomplished while completing each of these checkmarks set. Thus, this project was deemed successful and can be replicated by any third party. The estimated market value of the project – considering the quality and price of the individual components and materials used (This can be viewed in Appendix A of the report) – is capped at a price of GHC 210. This deduction was made with the targeted consumer market in mind, middle income Ghanaian households. For a consumer purchasing the Power Quality Analyzer, he/she is assured of a smooth, accurate and efficient experience of deducing the quality of power consumed by his/her devices.

6.2 Limitations

One core technical challenge faced with the construction of the Power Quality Analyzer was the abnormal overheating of some components soldered on the board. This problem was seen to stem out of the issue that these components received more voltage running through than expected and thus was corrected accordingly by redesigning those required parts of the circuit. With regards to the web app development to be used with the produced device, the created database responsible for collating all the required data for the respective quantities had to be manually uploaded unto the system after every testing period for new information to be accessed on the system. This is because, these data values were managed on a local database (on a specific computer) and thus did not include the function of automatic updates over the internet. In

addition, the country of Ghana faces a number of problems with its power generation as well as transmission with frequent power outages as a prevalent instance. Thus, collecting of the required quantities for measurement and analysis over a designated testing period was made difficult due to this problem.

6.3 Future Works

In the hope of advancing the system's performance and usage for better customer usability and experiences, the creation of an online database is in order to facilitate the automatic syncing of new and old data values of the required quantities to ease the stress of manually updating the system new information is received from the Power Quality Analyzer.

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Appendix A

Components Price List

Item	Quantity	Unit Price (USD)	Description	Package
PC817	4	0.12	Opto-Coupler for my project	DIP-4
IN4148	3	0.007	Diodes for my project	DO-35
LM78L05	2	0.394	Voltage Regulator for my project	TO-92(TO-92-3)
1N4742A	2	0.0279	Zener Diode	DO-41
I2C	2	0.0744	EEPROM	SOIC-8_150mil
1K Resistors	10		Resistors for my project	
10K Resistors	10		Resistors for my project	
10uF Capacitors	10		Capacitors for my project	
0.1uF Capacitors	10		Capacitors for my project	
KSC221JLFS	6	0.4718	Push button for my project	SMD
Infrared Reciever	2		Infrared receiver for my project	
MMBT2222	4	0.0237	NPN transistor for my project	SOT-23(SOT-23-3)
STC12C5A08AD-351-LQFP48	2	1.3293	IC Chip for my Project	LQFP-48_7x7x05P
C86503	2	0.0258	3 pin header for my project	Plugin
C278435	2	0.0889	8 pin header for my project	Through Hole, P=2mm
C86500	2	0.208	6 pin header for my project	Plugin
C267498	2	0.0693	2 pin header for my project	Through Hole
C83272	1	3.4906	2x16 LCD display for my project	Module
C24585	2	0.389	Relay for my project	5PIN
C5664	10	0.0074	Current shunt for my project	SIP - 2
C337156	5		Thermo resistor for my project	Axial
C8465	10	0.0954	Terminal Blocks for my project	DIP P = 5.08mm